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Energy related CO_2 emissions and the progress on CCS projects: A review

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A B S T R A C T

This review paper discusses the perspectives for development of carbon capture and storage (CCS) technologies in the global fight against climate change, such as low-carbon technology which is a vital component to reduce future carbon emissions. The information on the level and growth of CO_2 emissions, their source and geographic distribution, will be essential to lay the foundation for a global agreement; considering only for energy-related CO_2, and not for any other greenhouse gases. We analyzed the distribution of the CO_2 emission intensity related to them. Besides, in order to predict possible future situations of energy consumption, CO_2 emissions intensity and the CCS role like the largest emission reduction potential, the International Energy Agency (IEA) has developed a number of scenarios; the baseline scenarios and comparative scenarios. We used the approach of the Blue Map Scenarios, bringing the 2005s emissions to a level of 50% by 2050 for a non-catastrophic human intervention in the climate system. Moreover, this paper shows the barriers, strategies for accelerating and the stages in the technology deployment. We also analyzed the CCS projects status; Challenges, SWOT analysis, and the currently Global CCS Technology Activity. For this, we consider the Large Scale Integrated Projects (LSIP), and the asset life-cycle model was used to categorize the status of a project according to its development stage. Alongside, the analysis involves: Total LSIPs by geographic region, by Industry and CO_2 Capture Technology. In addition, we also made a scope on some of the most relevant international actions in order to stimulate the fulfillment of the CO_2 intensity target.

Contents

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1. Introduction

In recent years, the growing concern about the enormous negative impacts of energy generation and consumption has revived the interest in studying the energy structure and new low carbon technology development. Fossil fuels provide about 81% of all commercial energy as of 2009 [1]; which has been heavily implied for the rising concentrations of greenhouse gases in the earth's atmosphere that are expected to lead to significant changes in climate with serious economic and social effects.

Carbon dioxide emissions are believed to be responsible for approximately three-quarters to global greenhouse gases. For the first time in history, the share of CO_2 emissions from developing countries was in 2008, 50.3%; just larger than those of industrialized countries (46.6%), which have an emission mitigation target under the Kyoto Protocol, and from international transport (3.2%) together [2]. Fossil fuel combustion accounts for about 90% of total global CO_2 emissions in 2011 [3], excluding those from forest fires and the use of wood fuel.

1.1. Recognizing the urgency

Action on climate change is urgently needed. If no action is taken by GHG emitters, by the end of the century, the world could be 4 °C warmer than it was at the start of the industrial revolution [1]. The impact on agriculture, water security, and sea level rise would have dangerous consequences for communities around the world. Scientists consider a 2 °C temperature raise the limit of safety, which is where the world will be headed if countries make good on their current emissions reduction pledges. Getting there will take the action of countries like those in the PMR (The Partnership for Market Readiness) and those that follow their success.

On a global level, it is estimated that for each year of delay in taking appropriate policy decisions (steps towards green economy) costs an additional 500 billion US dollars, in terms of mitigation costs between now and the year 2030. The proposals by the government to alter any large-scale social-technical systems to enable sustainable development goals are highly uncertain policy projects [4].

1.2. Potential GHG reduction alternatives

Potentially, there is a wide range of ways to reduce emissions of greenhouse gases. In the case of CO_2, reductions can be achieved by:

- Reducing the demand for energy; that can be influenced by a number of means including fiscal measures and changes in human behavior.
- Altering the way in which it is used and changing the methods of production and delivering energy.

However, in the technical area, there are a number of distinct types of options for reducing emissions, as illustrated in Fig. 1 [5].

Depending on the fuel type and application, the utilization of carbonaceous fuels causes direct and indirect emissions of one or more of the following: SO_x, NO_x, particulate matter, trace metal and elements, volatile organic carbon and greenhouse gases (e.g. CO_2, CH_4, N_2O). Direct emissions are usually confined to the point of combustion of the fuel. Indirect emissions include those that arise from upstream recovery, processing and distribution of the fuel.

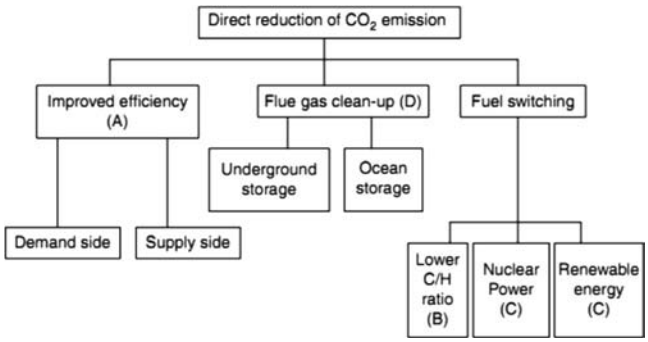


Fig. 1. Options of reduction CO_2 emissions – power generation system.

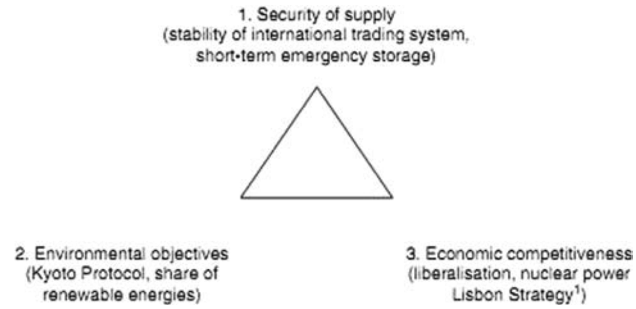


Fig. 2. The triangle of energy decision making [6].

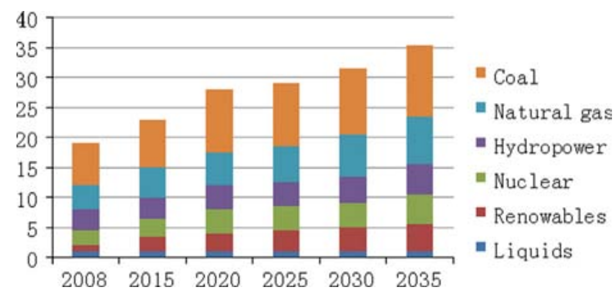


Fig. 3. World net electricity Gen. by fuel, 2008–2035 trillion KWh.

Accordingly, most of the efforts to mitigate global warming have concentrated on reducing CO_2 emissions, different technology option have been proposed and explored in order to achieve a sustainable low carbon energy society. CCS is one alternative in the portfolio of options for reducing greenhouse gas emissions that allows for the decreasing of atmospheric CO_2 emissions from relatively cheap fossil fuel-based power generation plants; also CCS enables the reduction of other pollutants like SO_x, NO_x, and particulate matters. As a safe and efficient method of capturing and storing billions of tonnes of CO_2 underground for thousands of years, CCS therefore represents the bridge to a truly sustainable energy system.

This paper intends to provide an overview of the CO_2 emissions caused by burning fossil fuels (coal, oil, natural gas) in the energy sector. Through the analysis of the approach taken by the BLUE Map Scenario, which reflects carbon emission trajectories under the current policy framework and under the new policy framework; we realize how CCS technologies will play an important role to achieve CO_2 reduction targets by the next decades. We also made a study on the barriers, the strategies for accelerating and the stages in the technology deployment. Moreover, we analyzed CCS status; Challenges, SWOT analysis, and the currently progress in LSIP – CCS projects by the global community. Alongside, we will review the main market mechanisms of reduction CO_2 insensitive in the CO_2 Markets.

2. Global energy

Energy questions have always played an important part in shaping the identity of modern world. Currently, is important to define and decide on the organization of trade-offs between three key policy objectives, which are energy security, industrial competitiveness and environmental protection (see Fig. 2).

Energy is considered a prime agent in the generation of wealth and a significant factor in economic development. Also is essential for improving the quality of life [7]. Electricity demand of a given geographical unit depends upon the size of the population, their life-style, climate, agriculture, industry, tourism, etc. Also, it is highly dependent upon the time of the day (e.g. the demand for air-conditioning is maximum at noontime).

There will be a higher demand for electricity between 2010 and 2030, especially in the developing regions of the world, due to a growing middle class and rapid urbanization. As the spending power of the people in those regions rises, so will their uptake of electric appliances.

2.1. Energy market overview

In 2011, China became the world's largest electricity producer with 21% of the total power generation, overtaking the United States (20% of the total), where power generation slightly decreased (−0.5%). With an 8.1% growth in power generation in 2011, India is catching up with Japan (5% of the global power production), where power generation fell by 4.7% following the March 2011 earthquake: Japan lost its position of third largest power producer to the advantage of Russia (5% of the total, +1.4% in 2011). Decreases in power generation in the United States, in Japan and in the European Union (−1.8% due to the economic crisis) reduced the share of OECD countries in the global production from 51% to 49%. Latin America posted an average 4.7% increase (+3.4% in Brazil, +6.8% in Mexico), while power generation grew by 3% in Africa (+1.1% in South Africa, +3.6% in Egypt) and by 4.4% in the Middle East.

Over the next two decades, the combined share of demand for electricity from the developed regions of European Union (EU), North America and Organization for Economic Co-operation and Development Asia Pacific (OECD APAC) will drop from 49.6% to 37.5%. However, power generation in the Middle East and Africa region will increase from 7.0% in 2010 to 7.9% in 2030. The bulk of demand growth is expected to come from India and China, with the combined share of only these two countries rising from 23.6% in 2010 to 34.5% in 2030. China's and India's role and future impact is most prominent in the area of coal-fired power generation, where they accounted for 43.8% of the world total in 2010, and this forecast will rise to 57.0% by 2030 [8].

According to the IEO2011 Reference case [9] the projections are as follows in Fig. 3:

- The World net electricity generation increases by 84%, from 19.1 trillion kilowatt-hours in 2008 to 25.5 trillion kilowatt-hours in 2020 and 35.2 trillion kilowatt-hours in 2035.
- Total net electricity generation in non-OECD countries increases by an average of 3.3% per year, led by non-OECD Asia (including China and India), where annual increases average 4.0% from 2008 to 2035. In contrast, net generation among OECD nations grows by an average of 1.2% per year from 2008 to 2035.
- In many parts of the world, concerns about security of energy supplies and the environmental consequences of greenhouse

gas emissions have spurred government policies that support a projected increase in renewable energy sources. As a result, renewable energy sources are the fastest growing sources of electricity generation at 3.1% per year from 2008 to 2035.
– Natural gas is the second fastest growing generation source, increasing by 2.6% per year. An increase in unconventional natural gas resources, particularly in North America but elsewhere as well, helps keep global markets well supplied and prices competitive. More than 82% of the increase in renewable generation is in the form of hydroelectric power and wind power. The contribution of wind energy, in particular, has grown swiftly over the past decade, from 18 gigawatts of net installed capacity at the end of 2000 to 121 gigawatts at the end of 2008; a trend that continues into the future.
– Electricity generation from nuclear power worldwide increases from 2.6 trillion kilowatthours in 2008 to 4.9 trillion kilowatthours in 2035, as concerns about energy security and greenhouse gas emissions support the development of new nuclear generating capacity. 75% of the world expansion in installed nuclear power capacity occurs in non-OECD countries. China, Russia, and India account for the largest increment in world net installed nuclear power from 2008 to 2035: China adds 106 GW of nuclear capacity over the period, Russia 28 GWs, and India 24 GW.
– Future generation from renewable, natural gas, and to a lesser extent nuclear power largely displaces coal-fired generation, although coal remains the largest source of world electricity through 2035.

2.2. Fossil fuels the world's top producers and users

Table 1 is showing the countries and their ranks of production and amount used for each fuels.

2.2.1. Oil

Today, about 30% of the world supply of crude oil comes from the Middle East. Another 18% comes from North America (this includes the United States, Canada, and Mexico) [10]. Saudi Arabia produces more oil than any other country in the world. Russia is the second leading oil producer, followed by the United States.

The United States, China, and Japan are the top consumers of oil in the world.

2.2.2. Natural gas

Currently, Russia and the United States are the top producers of natural gas in the world and also the main users. Gas is usually carried by pipeline. It can also be cooled and turned into a liquid called liquefied natural gas (LNG).

2.2.3. Coal

China is the world's largest producer and user of coal. Coal supplies about two-thirds of China's energy. The second-leading coal producer and user is the United States. Some coal mines are shallow, while others are deep underground.

2.3. Fossil fuel and electricity

2.3.1. Coal and electricity

Coal plays a vital role in electricity generation worldwide, as following in Table 2. Coal-fired power plants currently fuel 41% of global electricity [11].

Coal will remain the dominant fuel source despite Renewable Energy gaining ground. The importance of coal to electricity generation worldwide is set to continue, with coal fueling 44% of global electricity in 2030 [11].

2.3.1.1. Coal market sectors. Coal-fired power plants capacity to grow by 35% in next 10 years. World coal-fired power plant capacity will grow from 1,759,000 MW in 2010 to 2,384,000 MW

Table 2
Coal in electricity generation [11].

Coal in electricity generation		
South Africa 92%	Poland 94%	PR China 77%
Australia 76%	Kazakhstan 70%	India 69%
Israel 63%	Czech Rep 60%	Morocco 55%
Greece 52%	USA 49%	Germany 46%

Table 1
The world's top producers and users by 2007 [10].

Rank	Country	Production (in thousand short tons)	Rank	Country	Amount used (in thousand short tons)
World's top producers of coal			**World's top users of coal**		
1	China	2,795,462	1	China	2,772,799
2	USA	1,146,635	2	USA	1,127,998
3	India	527,228	3	India	590,823
4	Australia	435,690	4	Germany	281,316
5	Russia	345,795	5	Russia	243,960
		Production (thousand barrels per day)			**Amount used (thousand barrels per day)**
The world's top producers of oil			**The world' top users of soil**		
1	Saudi Arabia	10,248	1	USA	20,680
2	Russia	9874	2	China	7565
3	USA	8457	3	Japan	5007
4	Iran	4034	4	Russia	2820
5	China	3912	5	India	2800
		Production (in billion cubic feet)			**Amount used (in billion cubic feed)**
The world's top producers of natural gas			**The World's top users of natural gas**		
1	Russia	23,064	1	USA	23,047
2	USA	19,089	2	Russia	16,746
3	Canada	6335	3	Iran	3948
4	Iran	3952	4	Japan	3542
5	Norway	3270	5	Germany	3441

in 2020. Some 80,000 MW will be replaced. So there will be 705,000 MW of new coal-fired boilers built. The annual new boiler sales will average 70,000 MW. The annual investment will be $140 billion. These are the most recent forecasts in Coal-fired Boilers: World Analysis and Forecast published by the McIlvaine Company [12].Coal-fired power in Asia will rise to 1,464,000 MW in 2020 up from 918,000 MW this year. This will account for an increase in CO_2 of 2.6 billion tons.

So even if the US and Europe were to cut CO_2 emissions by far more than the targeted 20%, the total CO_2 increase from Asia will offset it by a wide margin. Coal-fired power in India will rise from 95,000 MW to 294,000 MW over the next 11 years. This accounts for the largest percentage rise (300) plus the biggest quantitative rise (199,000 MW). So India alone will increase CO_2 by 955 million tons per year. The US presently operates coal-fired power plants at a much lower efficiency than those in Europe. Many of the new Chinese power plants are highly efficient. A number of small old power plants have been replaced. However within the last decade China has increased capacity from less than 50% to more than 200% of the US capacity. Its CO_2 emissions far exceed those from US power plants. Since coal is also still burned in residential and commercial boilers, Chinese total coal burning CO_2 emissions far exceed the US.

China and India have coal resources. Other Asian countries have access to supplies from Australia and other nearby sources. The cost of coal-fired power is low compared to the alternatives in the near-term. Since planning of new coal-fired power plants occurs as much as a decade in advance, there is not likely to be a major change in the forecast through 2020. Any impact of renewable energy in Asia is only likely to happen after 2020.

2.3.1.2. Coal combustion pollutants. The National Emissions Inventory [13] prepared by EPA indicates that emissions to the atmosphere from coal-fired power plants:

- Contain 84 of the 187 hazardous air pollutant identified by EPA as posing to human health and the environment.
- Release 386,000 t of hazardous air pollutants annually that account for 40% of all hazardous air pollutant emissions from point sources, more than any other point source category, and
- are the largest point source category of hydrochloric acid, mercury, and arsenic release to air [14].
- Coal-fired power plants are also a major source of emissions for several criteria air pollutants; including sulfur dioxide, oxides of nitrogen, and particulate matter.

2.3.1.3. Hazardous air pollutant emissions. When talking about the emissions, one should keep in mind that besides CO_2, other pollutants such as particulate matters, SO_2, NO_x, etc., are also of great importance. In addition to air pollution problem, the CO_2 capture requires low amount of SO_2 and NO_x in flue gas. These emissions are dependent on the coal quality used and respectively the unit operations applied to control them.

HAPs emitted from coal-fired power plants include neurotoxins such as mercury and lead, corrosive substances such as hydrochloric acid, carcinogens such as arsenic and benzene, radioactive elements such as radium, and potent organic carbon-based toxins such as dioxins and formaldehyde. In addition to being the single largest class of total point source HAP emissions, coal-fired power plants are also a major source of emissions for many of these individual HAPs. As shown in Table 3 [14], combustion of coal to generate electricity is the predominant source of hydrochloric acid emissions to the atmosphere. Likewise, electricity generating stations powered by coal account for 46% of mercury, and 60% of arsenic released to the atmosphere from point sources.

Table 3
Contributions of coal-fired power plants to selected hazardous air pollutants emissions.

Hazardous air pollutant	Percentage of source emissions (%)
Acid gases (hydrochloric acid and hydrofluoric acid)	76
Arsenic	60
Berylium	28
Cadmium	30
Chromium	20
Cobalt	34
Lead	15
Manganese	11
Mercury	46
All non – mercury metal HAPs emitted by coal-fired power plants	25
Data obtained from USEPA, 2007	

2.3.2. Natural gas and electricity

The fastest growing use of natural gas today is for the generation of electric power. Natural gas power plants usually generate electricity in gas turbines, directly using the hot exhaust gases of fuel combustion. Single-cycle gas turbines generally convert the heat energy from combustion into electricity at efficiencies of 35 to 40%. Higher efficiencies of 50% or more are possible in natural gas “combined-cycle” (NGCC) plants. NGCC plants first use the combustion gases to drive a gas turbine, after which the hot exhaust from the gas turbine is used to boil water into steam and drive a steam turbine.

Low natural gas prices in the 1990s stimulated the rapid construction of gas-fired power plants. In 2003, natural gas passed coal as the energy source with the largest installed electricity generation capacity in the U.S. While natural gas-fired plants are among cheapest power plants to construct, their operating costs are generally higher than those of coal-fired power plants because the fuel is more expensive.

2.3.2.1. Environmental impacts of natural gas. Although natural gas is a hydrocarbon fossil fuel, the global warming emissions from its combustion are much lower than those from coal or oil. Natural gas produces 43% fewer carbon emissions than coal for each unit of energy delivered, and 30% fewer emissions than oil [15]. The full global warming impact of natural gas also includes “upstream” emissions from drilling gas wells, building pipelines, and processing raw gas. Much of these upstream emissions, however, consist of leakage of natural gas itself from pipelines and storage facilities. Methane, the main component of natural gas, is itself a strong warming agent. Compared with CO_2, methane is 25 times more effective at trapping heat over a 100 years′ timescale and 72 times more effective over a 20 years′ timescale [16].

2.3.2.2. Air pollution. Cleaner burning than other fossil fuels, the combustion of natural gas produces negligible amounts of sulfur, mercury, and particles. Burning natural gas does produce nitrogen oxides (NO_x), which are precursors to smog, but at lower levels than gasoline and diesel used for motor vehicles.

2.3.3. Oil and electricity

Power plants that burn oil to produce electricity are called oil-fired plants. They are no different in general principle and operation from their fossil-fueled relatives, the coal-fired and natural gas-fired plants, and are even similar to geothermal and nuclear power plants in some respects. The activities involved in producing electricity from oil begins with the extraction of the oil and ends with it being burned in boilers and turbines at power

Table 4
Net generation by energy source: (Thousand megawatt hours) [17].

Period	Coal	Petroleum liquids	Petroleum coke	Natural gas	Nuclear	Hydroelectric conventional	Total
2011	1,733,430	16,086	14,096	1,013,689	790,204	319,355	4,100,656
2012	1,517,203	13,209	9,691	1,230,708	769,331	276,535	4,054,485

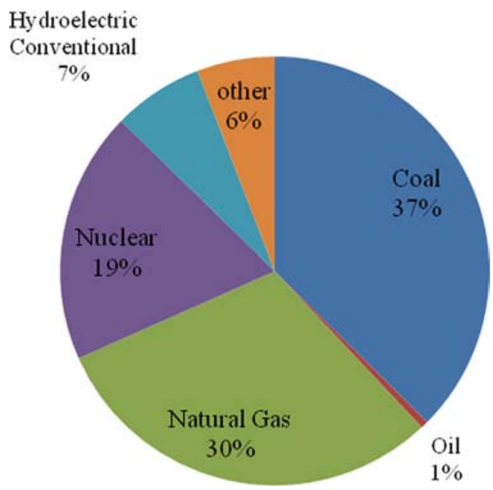


Fig. 4. Net Gen. by energy source: (Thousand megawatt hours).

plants. Initially, crude oil is removed from the ground by drilling deep wells and pumping it up to the surface. Oil is used mostly for transportation or home heating purposes, although a small percentage is used as a fuel for electricity generating plants.

2.3.3.1. Environmental impacts. Burning oil to generate electricity produces significant air pollution in the forms of nitrogen oxides, and, depending on the sulfur content of the oil, sulfur dioxide and particles. Carbon dioxide and methane (as well as other GHGs), heavy metals such as mercury, and volatile organic compounds (which contribute to ground-level ozone) all can come out of the smoke stack of an oil-burning power plant.

The operation of oil-fired power plants also impacts water, land use and solid waste disposal. Similar to the operations of other conventional steam technologies, oil-fired conventional steam plants require large amounts of water for steam and cooling, and can negatively impact local water resources and aquatic habitats. Sludge and oil residues that are not consumed during combustion became a solid waste burden and contain toxic and hazardous wastes. Drilling also produces a long list of air pollutants, toxic and hazardous materials, and emissions of hydrogen sulfide, a highly flammable and toxic gas. All of these emissions can impact the health and safety of workers and wildlife. Refineries, too, spew pollution into the air, water and land (in the form of hazardous wastes). Oil transportation accidents can result in catastrophic damage killing thousands of fish, birds, other wildlife, plants and soil.

2.3.4. Currently energy generation distribution (2012)

According to the data from EIA [17] until March 2013, the distribution is as follows in Table 4 and Fig. 4.

3. Carbon dioxide emission intensity

3.1. Global context

Globally, CO_2 is the most abundant anthropogenic greenhouse gas, accounting for 76% of total anthropogenic greenhouse gas emissions in 2008; the CO_2 emissions from fossil fuel use alone account for 62% of total GHG [16]. Electricity generation is by far the largest single source of CO_2 emissions (see Fig. 5).

Early indications suggest that CO_2 emissions trends in developing countries in 2013 will continue to increase, through growing consumption of fossil fuels in some of the larger countries.

3.2. CO_2 emissions by fuel

In 2010, 43% of CO_2 emissions from fuel combustion were produced from coal, 36% from oil and 20% from gas [18], as shown in next Fig. 6.

Between 2009 and 2010, CO_2 emissions from the combustion of coal increased by 4.9% and represented 13.1 Gt CO_2. Currently, coal fills much of the growing energy demand of those developing countries (such as China and India) where energy-intensive industrial production is growing rapidly and large coal reserves exist with limited reserves of other energy sources.

CO_2 emissions from oil represented 10.9 Gt CO_2 in 2010, an increase of 2.7%. The decreasing share of oil in total primary energy supply (TPES), as a result of the growth of coal and the penetration of gas, limited the increase of CO_2 emissions from oil. Emissions of CO_2 from gas in 2010 represented 6.2 Gt CO_2, 7.1% higher than in the previous year [18].

Without additional abatement measures, the WEO 2012 [19] projections by 2035 are as follows:

- Emissions from coal will grow to 15.3 Gt CO_2 in 2035. However, through use of more efficient plants and end-use technologies as well as increased use of renewable, nuclear and CCS technologies could see coal consumption drop and CO_2 emissions from coal reduced to 5.6 Gt.
- Emissions from oil will grow to 12.6 Gt CO_2, mainly due to increased transportation demand.
- Emissions from gas will continue to grow, rising to 9.2 Gt CO_2.

3.3. CO_2 emissions by region

Between 2009 and 2010, CO_2 emissions increased in all regions except Africa, however, growth rates varied among regions. CO_2 emissions from non-Annex I countries grew by 5.6%, while those of Annex I countries rose by a more modest 3.3%, having decreased in 2009. At the regional level (Fig. 7), between 2009 and 2010, CO_2 emissions increased significantly in Latin America (6.5%), Asia excluding China (6.1%) and China (6%). CO_2 emissions increased at a lower rate in Annex II regions, ranging from 2.1% in Annex II Europe to 3.4% in Annex II North America. Emissions in Africa remained stable [18].

Nearly two-thirds of global emissions for 2010 originated from just ten countries, with the shares of China (23.8%) and the United States (17.7%) far surpassing those of all others. Combined, these two countries alone produced 12.6 Gt CO_2, 41.5% of world CO_2 emissions (Fig. 8) [18].

3.4. CO_2 emissions by sector

As seen in Fig. 9, two sectors produced nearly two-thirds of global CO_2 emissions in 2010: electricity and heat generation accounted for 41% while transportation produced 22% [18].

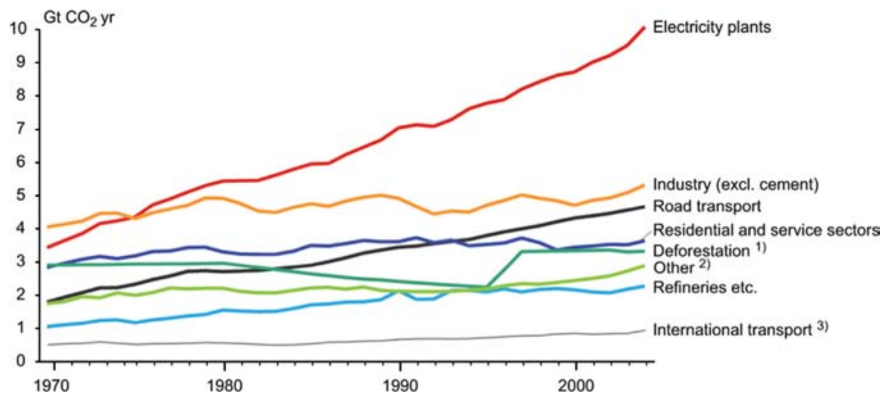


Fig. 5. Global CO_2 emissions by 1970–2004 direct by sector only.

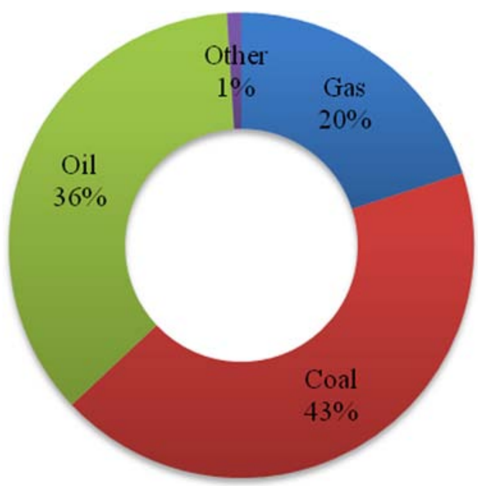


Fig. 6. CO_2 emissions by fuels.

The power generation sector plays an important direct role by reducing substantially its carbon intensity, but electricity now plays an indirect role by substituting for fossil fuels in all final demand sectors.

3.5. CO_2 intensity target for 2020

The USA announced a 17% CO_2 emission reduction target by 2020 from 2005 levels, 42% below 2005 levels by 2030 and 83% below 2005 levels by 2050. These targets are aligned with the energy and climate legislation passed by the House of Representatives. The EU and its member states are committed to an independent quantified economy wide emission reduction target of 20% by 2020, compared with 1990 levels. This target could be increased to 30% under conditions set out by the European Council [20].

In 2009, China government has announced to lower its CO_2 emission per unit of GDP (Gross domestic product) by 40%–45% by 2020 compared with the 2005 level, and to increase the share of non-fossil energy in primary energy consumption to 15% by 2020. China is currently in the period of accelerated industrialization and urbanization, with steadily rising energy demand, which means that China's CO_2 emissions will continue to increase in the short term. China is under high pressure and faces difficulties in controlling the growth of CO_2 emissions. As coal has dominated China's energy consumption, CCS has the potential to be an emission reduction option for China [21].

Its gets clear that it is not an easy task to achieve the carbon intensity target set for the global community.

4. Energy and CO_2 emissions under the baseline and BLUE Map scenarios

4.1. Scenarios and strategies to 2050

A very popular approach to dealing with the future is to construct several scenarios. Scenarios are self-consistent stories describing possible futures. The settings of scenarios include important information on society, economy, technologies, and lifestyles etc., which impact energy consumption and carbon emission. There are generally two types of scenarios-baseline scenarios and comparative scenarios, which reflect carbon emission trajectories under the current policy and a new policy framework, respectively.

4.2. Global CO_2 emissions related energy under the baseline and BLUE Map scenarios

The International Energy Agency (IEA) has developed scenarios; we use the approach of two of them, which are very different scenarios: Fig. 10 shows energy-related CO_2 emission reductions relative to the Baseline scenario (scenario without GHG mitigation policy) and the BLUE Map scenario [22].

The baseline global CO_2 emissions in 2050 are 57 Gt CO_2 being almost the double of the current emissions. Therefore, three quarters of the baseline global CO_2 emissions have to be reduced, meaning that the global CO_2 emissions have to be one quarter of the baseline emissions for halving the global CO_2 emissions by 2050.

In Fig. 11, the total emission reductions relative to the Baseline scenario in 2050 are 43 Gt CO_2, and the shares of emission reductions of electricity generation technologies are 19% by CCS, 17% by renewable, 6% by nuclear and 15% by improvements in efficiency and fuel switching among fossil fuels, respectively. Large emission reductions in energy end-use sectors (industrial sector, transportation sector and residential and commercial sector) are also required, and the share of these sectors is almost 38% of total emission reductions.

Reducing CO_2 emissions by 50% (from 2005 levels) by 2050 represents a tough challenge. This scenario implies a very rapid change of direction. Costs are not only substantially higher, but also much more uncertain, because the BLUE scenarios demand deployment of technologies still under development, whose progress and ultimate success are hard to predict.

The BLUE scenarios require urgent implementation of unprecedented and far-reaching new policies in the energy sector and the deployment of all technologies involving costs of up to USD 200 per tonne of CO_2 saved when fully commercialized. The progress of these technologies fails to reach expectations, costs may rise to as much as USD 500 per tonne. Additional investment needs in the BLUE Map scenario are USD 45 trillion over the period

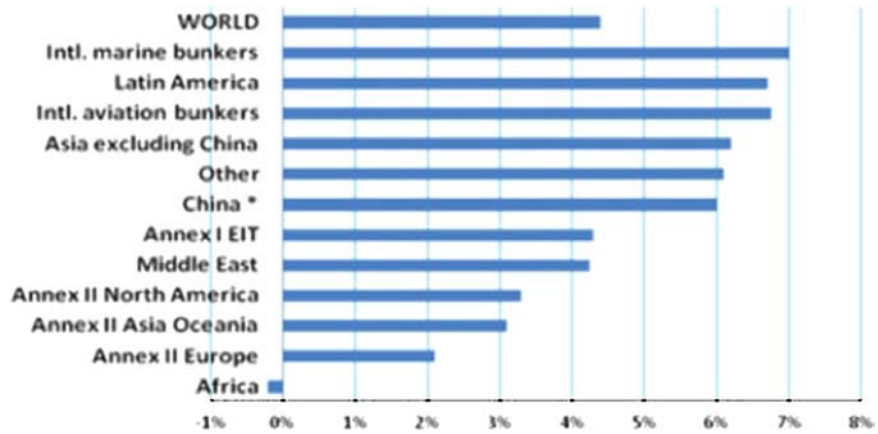


Fig. 7. % Change in CO_2 emissions by region (2009–10) [18].

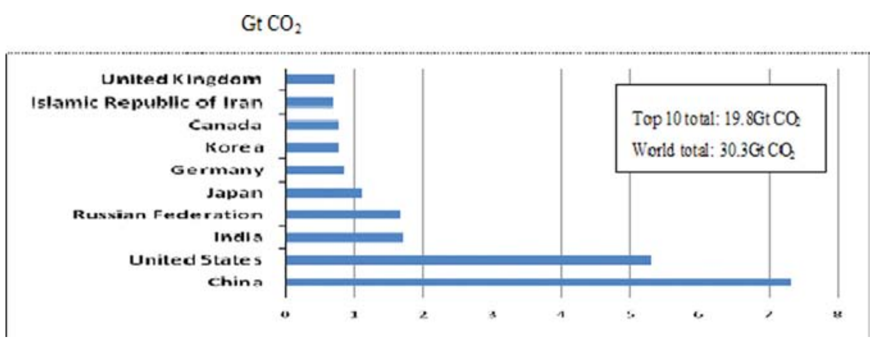


Fig. 8. Top 10 emitting countries in 2010 [18].

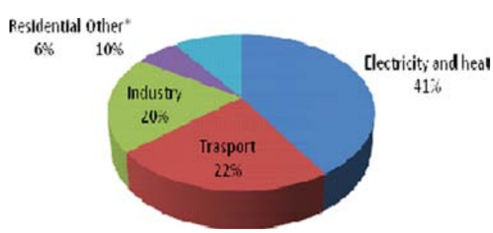


Fig. 9. World CO_2 emissions by sector in 2010 [18].

up to 2050. They cover additional R&D, larger deployment investment in technologies not yet market-competitive (even with CO_2 reduction incentives), and commercial investment in low-carbon options (stimulated by CO_2 reduction incentives). The total is about USD 1.1 trillion per year.

4.3. BLUE Map scenario CCS – CO_2 reduction targets

Under the BLUE Map scenario, global deployment of CCS is projected to capture over 10 Gt of CO_2 emissions in 2050, with a cumulative storage of around 145 Gt CO_2 and 3400 operating CCS projects from 2010 to 2050, as shown in Fig. 12.

Capture from power generation represents 5.5 Gt CO_2/year (or 55% of the total CO_2 captured) in 2050. Capture from industry accounts for 1.10 Gt CO_2/year (16%), and upstream capture (e.g., gas processing and fuels transformation) accounts for 2.9 Gt CO_2/year (29%) of the total in 2050 as seen in Fig. 13.

The BLUE Map scenario analysis estimates that growth in both demonstration and commercial scale CCS projects within the OECD regions will account for around two-thirds of the total CO_2 captured by 2020. However, the widespread deployment of CCS within power generation and industry in emerging economies will effectively decrease this share to 47% of the cumulative CO_2 stored by 2050. Within non-OECD regions, China and India will account for around 26% of the total cumulative amounts of CO_2 capture required. CCS development will start in the industrialized countries but is expected to rapidly shift to developing regions after 2020.

The numbers of CCS projects and the CO_2 Capture by region are shown in the Fig. 14. If the amount of CO_2 storage per site is assumed to be 3 Mt CO_2/year, the storage sites of 850 projects are needed in the world in 2030, and those of 3400 are needed in 2050 by the BLUE Map scenario

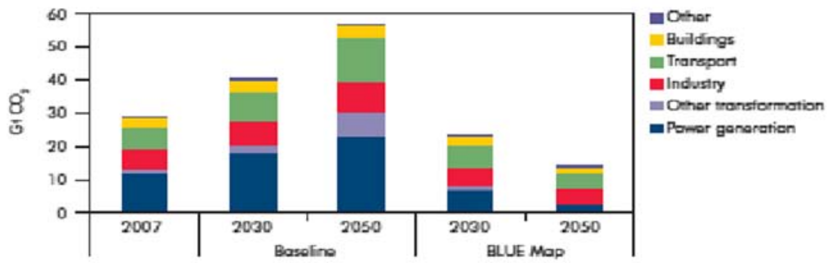
5. Research, development and demonstration of the low carbon technologies in the energy sector

Some large firms, like Siemens, General Electric and Toshiba, do undertake a vast, multidisciplinary RD&D effort which includes energy RD&D, but the precise breakdown of expenditure for energy RD&D is not known. The RD&D intensity of the total RD&D in the case of power sector is estimated to be 0.5%. This is much less than RD&D intensity of automobile industry (3.3%), electronics industry (8%) and pharmaceutical industry (15%). Private sector spending in RD&D in energy-related sectors (USD 40–60 billion/year) is four to six times more than governmental spending in the sectors [5].

5.1. Barriers of technology diffusion

The rate of technology diffusion depends upon the following market characteristics for individual products:

– rate of growth of the market, and the rate at which the old capital stock is phased out,



Baseline Scenario: No new policies are introduced between now and 2050.	BLUE Map Scenario: Global energy-related CO_2 emissions are reduced to half their 2005 levels by 2050, and are broadly optimistic for all technologies.

Fig. 10. Energy-related CO_2 emission rel. to Baseline and BLUE MAP.

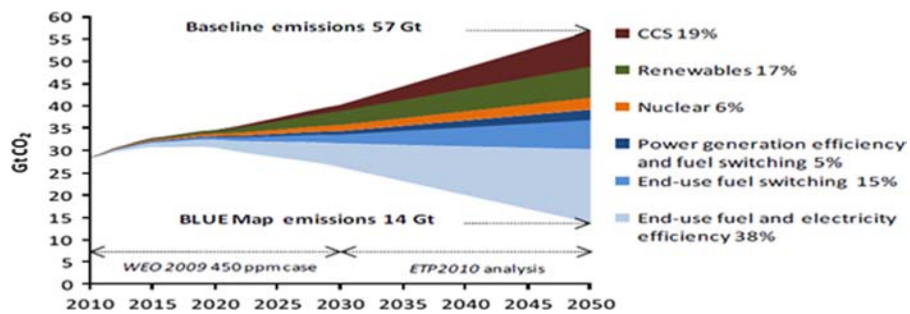


Fig. 11. The total emission reductions rel. to Baseline S. in 2050.

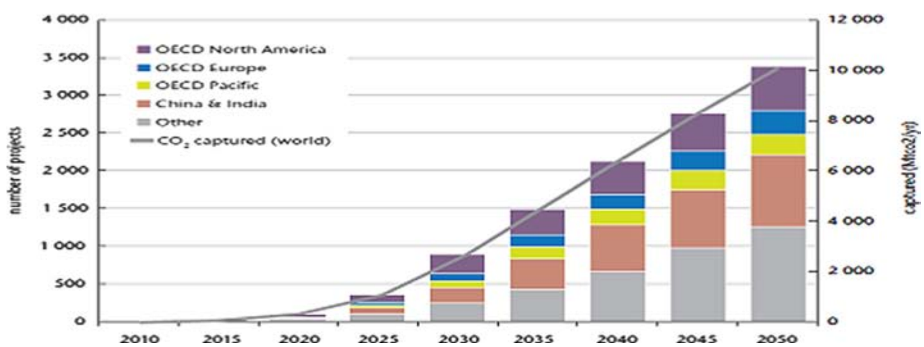


Fig. 12. CO_2 captured and number of CCS projects 2010–2050.

- the rate at which new technology can become operational,
- the availability of a supporting infrastructure, and
- the viability and competitiveness of alternative technologies.

Other factors that have a bearing on the rate of diffusion are: government policy in phasing out of constraining standards and regulations, and introduction of new technologies, availability of skilled personnel to produce, install and maintain new equipment, ability of the existing suppliers to market new equipment, dissemination to the consumers of concerned information, and incentives for buying, of new equipment, and extent of compliance with regulations and standards.

Rapid diffusion of technology needs the removal of the following barriers:

- investors are not induced to invest due to the non-availability of clear and persuasive information about a product,
- transaction costs (i.e. indirect costs of a decision to purchase and use equipment) are high,
- buyer perceives a risk higher than it actually is,
- costs of alternative technologies are not correctly estimated, and market access to funds is difficult,
- high sunk costs, and tax rules that favor long depreciation periods,
- excessive/inefficient regulation which does not keep pace with emerging situation,
- inadequate capacity to introduce and manage new technology, and
- non-realization of the benefits of economy of scale and technology learning.

5.2. Strategy for accelerating deployment

The development of policy by the government should take into consideration the following criteria:

- Attribution of proper cost to the CO_2 impact of individual technologies,
- assurance of policy support to clean technologies, with modifications as the situation on the ground changes,



Fig. 13. Capture of power generation and Industry of CCS 2010–2050.

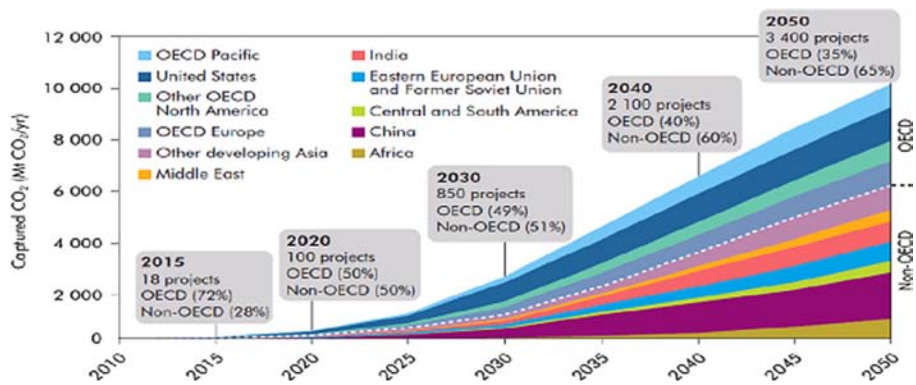


Fig. 14. Captured CO_2 by region in the BLUE Map scenario [22].

Table 5
The states in the technology deployment [5].

R&D	Demonstration	Deployment	Commercialization
Seeks to overcome technical barriers and reduce costs. Commercial outcomes are highly uncertain, especially in the early stages.	The technology is demonstrated in practice. Costs are high. External (including government) funding may be needed to finance part or all of the costs of demonstration.	Successful technical operation, but possibly in need of support to overcome cost or non-cost barriers. With increasing deployment, technology learning will progressively decrease costs.	The technology is cost competitive in some or all markets, (diffusion) either on its own terms, or where necessary, supported by government intervention (e.g. to value externalities, such as costs of pollution).

- encourage industry to stand on its own, i.e. without direct support from the government – overgenerous support policies may stifle innovation.
- governments can promote commercialization of energy-efficient technologies through codes and standards, non-binding guidelines, fiscal and financial incentives, etc.

5.3. The stages in the technology deployment

The stages in the technology deployment are schematically shown as follows in Table 5.

On the demand side, economically-viable technologies which are capable of delivering two-thirds of the needed reduction in CO_2 emissions already exist. The commercialization of these technologies cannot take place without the support of the government. Though the technologies are cost effective, they have not penetrated the market, as the consumers tend to take a short-term view of costs rather than long-term life-cycle costs.

The Low carbon technologies need to be developed in a short term (i.e. 10–15 years) as is shown in Fig. 15. The *X*-axis shows the stages in technology development of the Low Carbon and Renewable Technologies (Basic Science, Applied R&D, Demonstration, Deployment, and Commercialization) while the *Y*-axis shows the CO_2 saving achieved by ach technology cluster.

The global energy economy needs to be transformed profoundly in the coming decades in terms of ways by which energy is supplied and used. This is to be accomplished through greater energy efficiency, greater use of renewable and nuclear power, CO_2 Capture and Storage on a massive scale, and development of carbon-free transport. Among these, improvement in energy efficiency is the least expensive and most effective pathway.

6. CCS technology status

6.1. Carbon capture and storage (CCS)

CCS is a technology that can reduce the amount of CO_2 released into the atmosphere from the use of fossil fuel in power plants and other industries such as from steel, cement and ammonia manufacture. CCS involves three main stages (see Fig. 16), each with its own set of technologies:

- collecting or capturing the CO_2 produced at large industrial plants using fossil fuel (coal, oil and gas) or other carboniferous fuels (such as biomass). This is the first stage, to be done in several ways. Broadly, three different types of technologies exist: post-combustion, pre-combustion, and oxyfuel combustion, in which the point of focus is towards cost reduction, currently accounting for up 80%

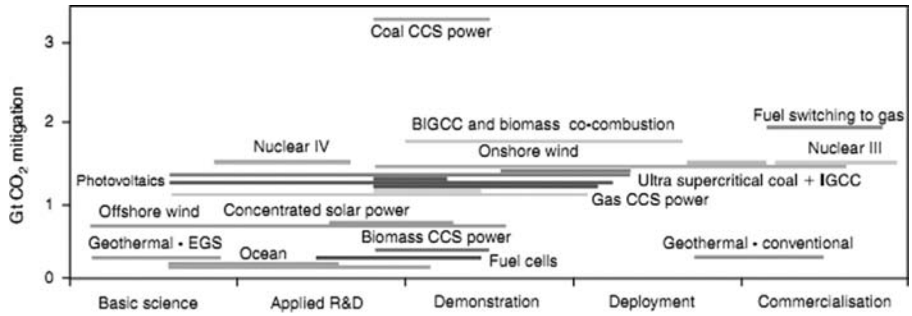


Fig. 15. CO_2 saving achieved by technology clusters [5].

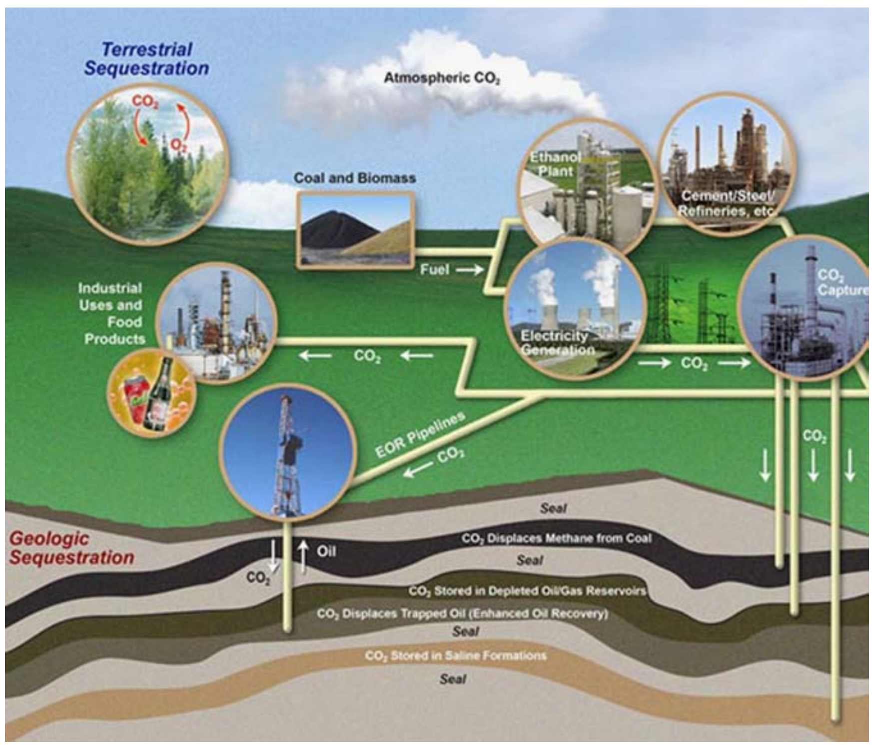


Fig. 16. Scheme of CCS [23].

of full CCS chain costs, but still the option for offshore CO_2 reinjection and sequestration; since CO_2 has separated for natural gas commercialization; for avoiding long transportation costs; and possibly enhancing oil recovery, incurring lesser costs than full CCS chains applied in onshore industries or power plants
– transportation of the CO_2 to a suitable storage site, and
– pumping it deep underground into rock to be securely and permanently stored away from the atmosphere.

There has not yet been industrial scale demonstration or operation of CCS technologies for commercial power generation. Consequently there are significant research and development efforts being pursued in a number of countries. However it is unlikely that CCS will be commercially available for large-scale deployment before 2020.

6.2. CCS challenges

CCS technology faces many challenges to successful, full scale demonstration and commercial deployment including issues such as:

– Financing large scale demonstration projects and
– integration of CCS into GHG policies;

The higher cost and efficiency penalty of CCS technologies; development and financing of adequate CO_2 transport infrastructure; development of legal and regulatory frameworks to ensure safe, permanent CO_2 storage; adequate public consultation; and developing capacity and awareness in rapidly growing fossil based economies. There is a large and growing body of work underway to address these issues at international and national levels.

However, the critical next step is to verify the performance of CCS at scale, with capture from a variety of different industries and storage in a variety of geologic settings. To date, only a few large scale CCS projects are in operation.

There is also a need to ensure widespread CCS development in a variety of settings. Thus, the following guiding principles should help to shape the global portfolio of CCS projects:

i. CCS projects need to be:
   – Demonstrated at scale in all major fossil based economies, including emerging economies.
   – Designed to maximize knowledge sharing via transparent and regular publication of results.
ii. CO_2 capture needs to be demonstrated:
   – Using a variety of CO_2 capture technologies.

- At a variety of point sources, including coal and gas fired power plants, refineries, chemical plants; cement plants, iron and steel manufacturing facilities, and other industrial operations.
- Through retrofitting at a coal fired power plant (this is an urgent need).
- Using biomass input (this offers an important carbon reduction opportunity, and should be pursued urgently).

iii. CO_2 transport needs to be enhanced:
- Through deployment of infrastructure.
- By applying effective design and regulation of networks.

iv. CO_2 storage needs to be demonstrated:
- In a wider set of projects with different geologic settings.
- Enhanced oil and gas recovery offer cost effective opportunities for CCS demonstration, and should be pursued as an early opportunity.

v. Climate change legislation must not be delayed.
vi. In order to achieve emission reductions in the most efficient and effective way CCS must not be disadvantaged.
vii. Funding for CCS demonstration projects should be accelerated.
viii. Expertise and learning must be shared.

6.3. CCS SWOT

Strengths are the strong parts of the organization that can be directly controlled. Weaknesses, on the other hand, are those elements of the organization that are not positive but CCS can also control, so these represent areas that CCS can improve itself. Opportunities and threats operate outside the organization and while they are usually beyond control, CCS can perhaps influence their impact.

CCS strengths

- CCS technologies are now widely recognized as the most promising and the only nearly commercially viable technology available to disassociate CO_2 emissions from fossil fuel usage at scale. CCS is included in all cost effective climate change mitigation strategies of the International Energy Agency (IEA) and the Intergovernmental Panel on Climate Change. The IEA [24] estimates that CCS can contribute 19% of the emission reduction needed to constrain a rise in global temperature to within the agreed limit of 2 °C. According to the IEA, the cost of achieving the same emission reduction without CCS would be 70% higher.
- CCS has been used successfully in oil and gas industries for decades and aggressive international efforts are underway to demonstrate CCS in coal and NG-based power plants.
- New economy growing opportunity.
- Technology innovation and advancement.
- Optimization of de development mode.
- Cleaner environment and more sustainable ecology.

CCS weaknesses

- Advances in technology are notoriously unpredictable. It is not possible to predict the cost of natural gas from hydrates below the ocean floor in 50 years from now. It is equally difficult to predict whether coal seams 2000 m below the ground will remain unmineable. Neither the gas hydrates nor the deep seams are counted in today`s resources estimate.
- There is the potential for schedule delays associated with the development of a particular element of the CCS chain lagging behind. For example, if the development of a transport and storage network is delayed, this also imposes significant delays to the capture plant project.

CCS opportunities

- Fossil fuel resources are large enough and fossil fuel technology is sufficiently developed, playing a major role in providing for the world′s growing energy demand.
- Demonstrating CCS in developing countries dependent on fossil fuels is now viewed by all stakeholders as essential to making its deployment likely and to decarbonizing their power sectors.
- Develop Capture and storage technologies will be a new business opportunities from a technological point of view. As for CO_2 capture processes, a whole new industry needs to be created for the market in both the industrialized and developing countries. We shall take the opportunity as the country is making efforts on energy conservation and emission reduction and on the expansion of their applications in various sectors.
- The development of renewable energy resources will definitely increase the consumption of fossil energy because wind and solar energy resources are intermittent by nature. This means that electricity will be generated only when there is wind or sunlight, but production and utilities also need electricity and with even greater demands when the wind or sunlight is absent. To make the most use of wind power and solar photovoltaic, the installed capacity of thermal power must be increased to guarantee a steady and sufficient supply of energy, and this requires more coal power to be developed.

CCS threats

- CCS is not approved being included in emission reduction mechanism because of the high uncertainty of the technology itself. Climate change regulations do not include explicit definitions on CCS. Furthermore, different emission reduction mechanisms (CDM, JIT and ET) stated in the Kyoto Protocol did not include CCS either. So the definition of CCS technology will be an important question in future climate negotiations. The largest challenge for CCS in the future is the lack of consensus on long-term targets. Without such clear target, it will be difficult for countries to employ CCS technology at large scale.
- There are many alternative technologies which can also contribute to emission reduction on a large scale. CCS has a lower competitiveness than wind power. Whether CCS can be a viable option depends mainly on its cost. Currently, in China the generating cost will increase a lot after retrofitting with CCS. Domestic coal fired power generation cost will increase by 2–3 times after retrofitted with CCS. In 2005, the cost of domestic coal fired generation was 0.23–0.28 RMB $(kWh)^{-1}$, after being retrofitted with CCS the cost will increase to 0.4–0.8 RMB $(kWh)^{-1}$, while the generating cost of wind power is 0.35 RMB $(kWh)^{-1}$ [25].
- Rising fossil-fuel prices.

6.4. Global CCS technology activities

Projects can be analyzed according to their level of integration – from capture, to transport, and storage. Some projects focus exclusively on the capture, transport or storage of CO_2, while other projects are broader in scope and may include a combination of components or cover the full CCS chain and be considered fully integrated.

6.4.1. LSIPs (Large Scale Integrated Projects)

According to the Global Status of CCS: 2012 [26], LSIPs are defined as projects involving the capture, transport and storage of CO_2 at a scale of:

- at least 800,000 t of CO_2 annually for a coal-based power plant; or
- at least 400,000 t of CO_2 annually for other emission-intensive industrial facilities (including natural gas-based power generation).

The thresholds listed above correspond to the minimum volumes of CO_2 typically emitted by commercial-scale power plants and other industrial facilities. Projects at this scale must

store anthropogenic CO_2 permanently in geologic storage sites to qualify as LSIPs, and projects that involve EOR using anthropogenic CO_2 can also satisfy this definition. Since there is currently no clear standard or regulatory guidance on monitoring requirements involving CO_2 storage associated with EOR, criteria regarding monitoring expectations for CO_2 EOR are not included in the current LSIP definition. Generally, CO_2 EOR projects will undertake some monitoring and the monitoring methods will be site-specific.

This definition of LSIPs will be regularly reviewed and adapted as CCS matures; as clear CCS legislation, regulation, and standards emerge; and as discussions progress on project boundaries, life-cycle analysis, and acceptable use of CO_2. Additionally, there are many projects around the world of a smaller scale (or which focus on only part of the CCS chain) that are important for research and development (R&D), for demonstrating individual elements of CCS and building local capacity.

6.4.1.1. LSIP in 2012. The Global CCS Institute identified 75 large-scale integrated CCS projects globally, as at September 2012, as shown in Table 6.

- There are seven LSIPs that are considered on-hold or cancelled since the 2011Status report [27].
- Nine newly-identified projects were added to the listings and another eight projects were removed due to have been canceled, put on hold, or restructured. The most frequently cited reason for a project being put on-hold or canceled is that it was deemed uneconomic in its current form and policy environment. The lack of financial support to continue to the next stage of project development and uncertainty regarding carbon abatement policies were critical factors that led several project proponents to reprioritize their investments, either within their CCS portfolio or to alternative technologies.
- More than half of all newly-identified LSIPs are located in China. All newly-identified projects are investigating EOR options, at least as an additional source of revenue.
- In general, moderate progress was made by projects this year, with those at the more advanced planning stages making the most progress. There have been two additional projects identified as under construction, in the US and in Canada.
- The first peak in large-scale projects coming online that was expected to occur in 2015–16 has shifted over the past two years and is now projected to start from 2018–20.

6.4.2. LSIPs – the Worley Parsons asset lifecycle model

The asset life-cycle model is used to categorize the status of a project according to its development stage. This model is a framework to assist decision-makers and articulates a staged approach with a series of “go/no go” decision gates. The asset life-cycle model is shown in Fig. 17.

The status of CCS projects has been grouped into the following categories:

- Planned projects are in the Identify, Evaluate or Define stage of the asset life-cycle prior to sanction.

Table 6
Status of LISPs.

Year	Total LSIPS	Cancelled	On-hold	Newly identified	Other removed
2011	74	3	8	8	–
2012	75	5	2	9	1

- Active projects are in the Execute or Operate stage of the asset life-cycle after having been sanctioned. It is important to note that active does not necessarily mean that a project is operating or actively injecting CO_2 for storage.

As shown in Fig. 18, most the LSIPs are in the evaluate phase (32%), so this means at they are in Pre- feasibility studies (Design, Cost estimates, etc); the Europe area has the majority of them with eight. Followed by projects in Define phase (28%); USA is the most active in this phase with nine projects. For China the largest number of LISPs (9) are in identify phase, those are nine; as shown in Fig. 19.

6.4.3. LSIPs by region

The distribution of projects by region is shown in Fig. 20, and is:

- USA has the most projects of any region, with 24 LSIPs CCS projects.
- Europe area with 21 LSIP CCS projects has the second highest number. This can be largely attributed to the 2007 commitment by the EU to construct 10 to 12 full-scale CCS demonstration plants by 2015. The viability of these projects will need to be assessed as part of the EU competitive bidding process.
- Australia has 5 projects within this subset, of which one is in the Execute stages.
- Canada has 8 LSIP CCS projects most of them are in Define (3) and Execute (3) phase.

As seen in Table 7, there are currently 8 operational commercial-scale CCS plants globally; the largest numbers of LISPs are in USA.

6.4.4. Distribution LSPs by industry and CO_2 capture technology

Of the 75 LSIPs, 42 occur in the power generation sector and most of these are planned to occur in coal-fired applications. This level of activity in the power generation sector is commensurate with the need to reduce emissions from this sector through the application of CCS. Followed by Natural Gas processing (11) and Synthetic Natural Gas processing (6) as seen in Fig. 21.

According to the Fig. 22, distributions of LSIPs by capture technology are as follows:

In the largest category of pre-combustion capture, 14 out of 39 projects are in the power generation sector. For post-combustion capture, the 19 projects are in the power generation sector. Oxyfuel combustion, the third major type of CO_2 capture technology, is being planned or considered by 6 LSIPs. The remainder is spread out between Gas processing, fertilizer production and other refining facilities.

Fig. 23 is showing the distribution of LSIPs by region and Capture technology; USA and Canada have the Pre-Combustion as the most popular Capture technology with 19 and 6, respectively. By EU, Post-Combustion is more widespread with 11 LSIPs; for other countries the distributions between capture technologies are similar.

6.4.5. Newly-identified LSIPs

Five new early-stage LSIPs were identified in China since 2011, three of which are in the power generation industry. While pre-combustion capture is currently the most frequently used technology in China [26], investments in the testing of Oxyfuel combustion capture are increasing. All proponents of large-scale CCS projects in China are investigating EOR options, at least as an additional source of revenue. Newly identified LSIPs are listed below in Table 8.

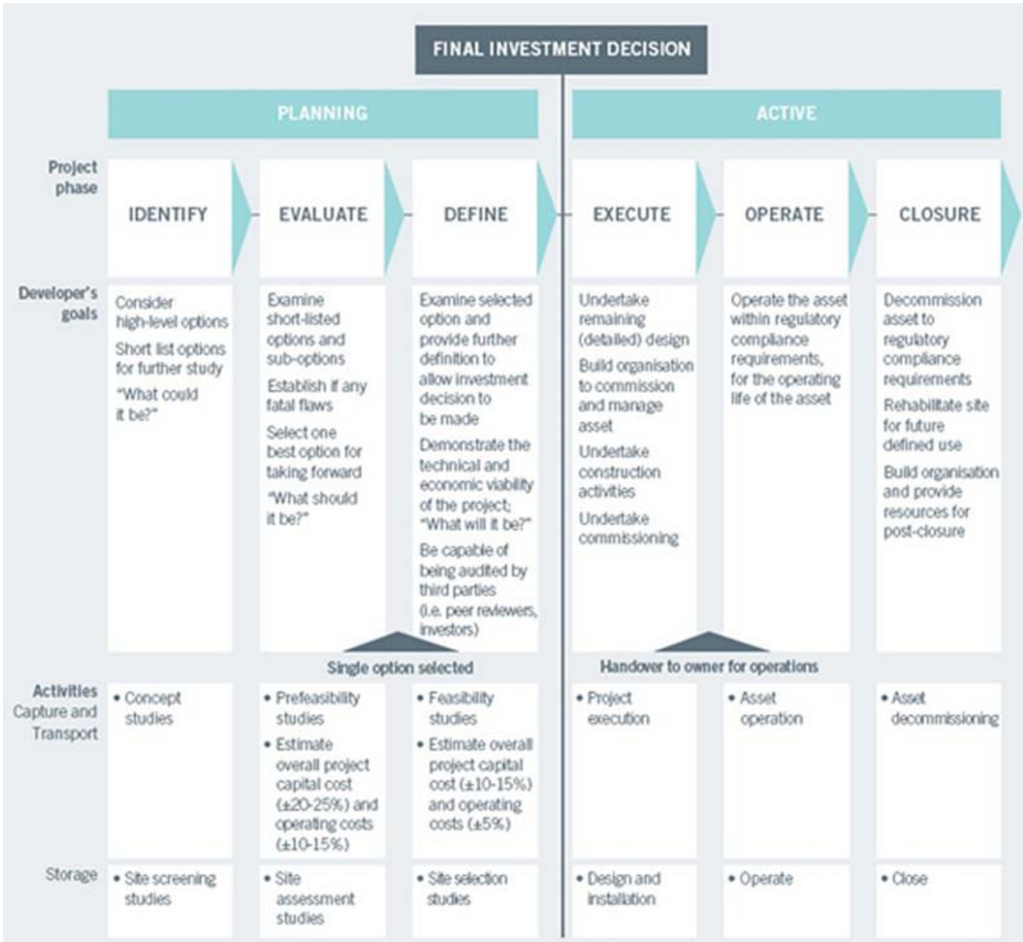


Fig. 17. The Worley Parsons asset life-cycle mode [26].

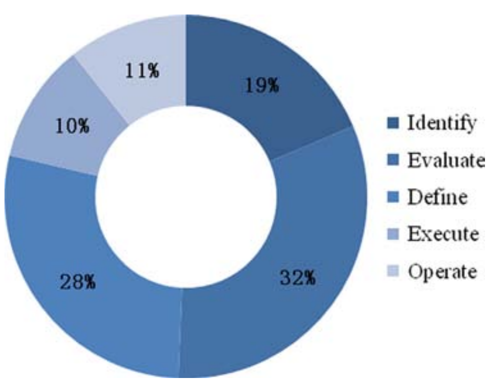


Fig. 18. LSIPs by asset lifecycle.

7. The future of CO_2 markets – international action

In order to address climate change and reduce greenhouse emissions, international negotiations on these issues are not only viewed from environmental but also from political, economic, and diplomatic perspectives. Thus, many organizations and countries are joining forces to achieve common goals. At the same time market mechanisms of reduction CO_2 intensities were already created.

7.1. The partnership for climate solutions

Is a coalition of more than 30 developed and developing countries that began working together in 2010. The partnership for market readiness (PMR) is made up of about a dozen contributing participants, including Australia and Japan, and 16 implementing countries, including China and Chile. The implementing countries are designing proposals in order to receive grant funding. Approaches vary by country, but the common element is using cost-effective, market-based instruments to lower carbon emissions and building the readiness infrastructure to get there [28].

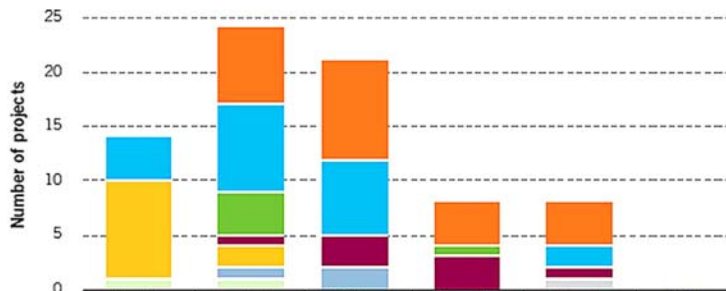
The PMR provides a platform for countries to learn from one another experiences, and explore and implement innovative approaches to greenhouse gas mitigation, far from the tense international negotiations connected with the United Nations Framework Convention on Climate Change (UNFCCC).

"These countries, learning from past lessons, are exploring and implementing markets-based approaches to tackling climate change," said Xueman Wang, Team Leader of the PMR. "Their success will be crucial to scaling up mitigation efforts."

Other countries are also laying the ground for future market instruments that could reduce their greenhouse gas emissions cost effectively. "China is determined to pursue a low-carbon development. Addressing climate change is an important opportunity for transformation to a green and low carbon economy, China hopes to develop its own carbon market with the support of the PMR, an experience which will provide other countries with lessons learned."

7.2. Market mechanisms of reduction CO_2 intensities

There are the mandatory market and a voluntary market. The most used by, already operates plants.



	Identify	Evaluate	Define	Execute	Operate	Total
United States	0	7	9	4	4	24
Europe	4	8	7	0	2	21
Australia and New Zealand	0	4	0	1	0	5
Canada	0	1	3	3	1	8
China	9	2	0	0	0	11
Middle East	0	1	2	0	0	3
Other Asia	1	1	0	0	0	2
Africa	0	0	0	0	1	1
Total	14	24	21	8	8	75

Fig. 19. LSIPs by asset life-cycle and region/country [26].

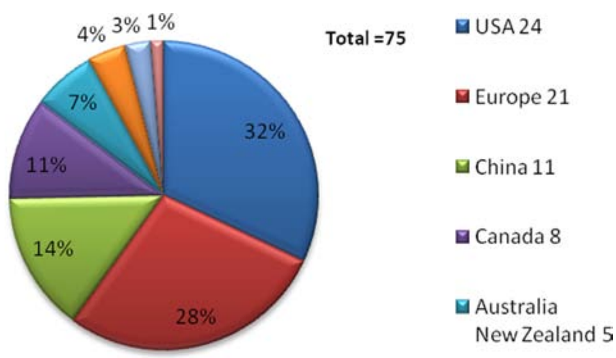


Fig. 20. Total LSIPs by geographic region.

7.2.1. *Voluntary emission reductions or verified emission reductions (VERs)*

Also known as carbon offsets, are designed for companies looking to reduce the environmental impact of their flying, driving, and some heating and manufacturing methods with real, verified and permanent carbon reductions. A VER represents the reduction of one metric ton (2205 lbs) of carbon dioxide or its equivalent. Each ton of emissions reduced by a carbon reduction project results in the creation of one VER, a commodity sold to finance these projects [29].

VERs are emission credits which are generated outside of the Kyoto protocol and cannot be used within the Kyoto Protocol or the EU ETS (European Union Emissions Trading Scheme). VERs are derived from project-based emissions reductions from a wide range of technologies and project types. There are three main market drivers for demand in the voluntary market.

– Firstly, as a key component of a company's marketing strategy linked to corporate social responsibility
– secondly, as a profit-making enterprise where financial participants build portfolios of VERs in order to obtain returns on capital employed, and
– thirdly, as a valuable learning exercise for forward looking companies and investors who anticipate future participation in the compliance regime.

7.2.2. *The clean development mechanism (CDM)*

Is one of the flexibility mechanisms defined in the Kyoto Protocol that provides for emissions reduction projects which generate certified emission reduction (CER) units which may be traded in emissions trading schemes [30].

The CDM is defined in Article 12 of the Kyoto Protocol as one of the flexibility mechanisms that provides for emissions reduction projects which generate Certified Emission Reduction units that may be traded in emissions trading schemes, and is intended to meet two objectives:

(1) to assist parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the UNFCCC, which is to prevent dangerous climate change; and
(2) to assist parties included in Annex I in achieving compliance with their quantified emission limitation and reduction commitments (GHG emission caps).

The CDM addresses the second objective by allowing the Annex I countries to meet part of their emission reduction commitments under the Kyoto Protocol by buying Certified Emission Reduction units from CDM emission reduction projects in developing countries. The CDM allows industrialized countries to buy CERs and to invest in emission reductions where it is cheapest globally. Between 2001, which was the first year CDM project could be registered and 7 September 2012, the CDM issued 1 billion Certified Emission Reduction units. As of 1 September 2012, 63% of all CERs had been issued for projects based on destroying either HFC-23 (42%) or N_2O (21%). CCS was included in the CDM carbon offsetting scheme in December 2011.

8. Conclusions

(1) Current trends in energy supply and use are patently unsustainable – economically, environmentally and socially. Without decisive action, energy-related emissions of CO_2 will be more than double by 2050. The transition from the global system of fuel-based electricity generation to low GHG emission energy technologies is required to mitigate climate change in the long term. It appears that there is no quick fix; energy system transitions are intrinsically slow. During a transition, energy is used both to create new infrastructure and to satisfy other energy demands, resulting in additional emissions. Otherwise the amount of electricity generated by a country, and the breakdown of that production by type of fuel reflects the

Table 7
LSIPs operate stage in 2012 [26].

LSIP no. 2012	Overall asset lifecycle stage	Project name	District	Country	Industry	Capture type	Million tones, CO_2 annually
1	Operate	Val Verde Natural Gas Plants (1972)	Texas	United States	Natural gas processing	Pre-combustion (gas processing)	1.3
2	Operate	Enid Fertilizer CO_2-EOR Project (1982)	Oklahoma	United States	Fertilizer production	Pre-combustion	0.7
3	Operate	Shute Creek Gas Processing Facility (1986)	Wyoming	United States	Natural gas processing	Pre-combustion (gas processing)	7
4	Operate	Sleipner CO_2 Injection (1996)	North Sea	Norway	Natural gas processing	Pre-combustion (gas processing)	1
5	Operate	Great Plains Synfuel Plant (2000) and Weyburn-Midale Project	Saskatchewan	Canada	Synthetic natural gas	Pre-combustion	3
6	Operate	In Salah CO_2 Storage (2004)	Wilaya de Ouargla	Algeria	Natural gas processing	Pre-combustion (gas processing)	1
7	Operate	Snøhvit CO_2 Injection (2008)	Barents Sea	Norway	Natural gas processing	Pre-combustion (gas processing)	0.7
8	Operate	Century Plant (2010)	Texas	United States	Natural gas processing	Pre-combustion (gas processing)	8.5

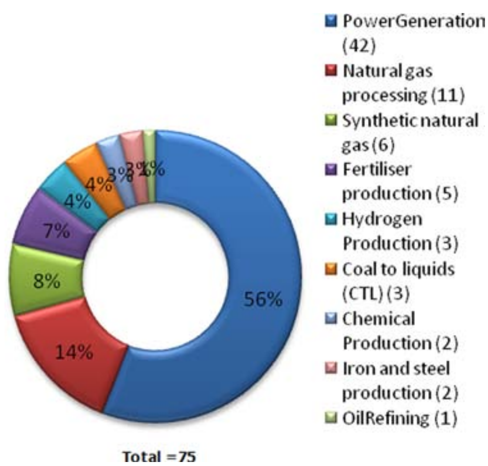


Fig. 21. LISPs by industry sector in 2012.

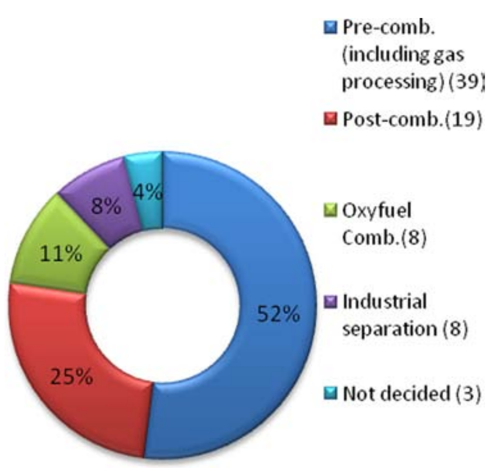


Fig. 22. Distribution LSIP by capture technology.

natural resources, imported energy, national policies on security of energy supply, population size, electrification rate as well as the stage of development and rate of growth of the economy in each country.

To meet the rising demand for electricity, the world's installed power generation capacity is expected to have grown by the next decades. All fuel sources, apart from oil, will expand, but coal will remain the dominant fuel source throughout the next two decades.

(2) The world's total emissions for 2010 was 30.3 Gt CO_2,and nearly two-thirds of them are originated in just ten countries, with the shares of China (23.8%) and the United States (17.7%) far surpassing those of all others. Combined, these two countries alone produced 12.6 Gt CO_2, 41.5% of world CO_2 emissions. Currently, coal is now the most growing fuel energy demand of those developing countries (such as China and India), where the energy-intensive use on industrial production is growing rapidly and large coal reserves exist with limited reserves of other energy sources. Electricity and heat generation account for 41% while transportation produces 22% of CO_2 emissions. According to the Blue Map Scenarios, by 2050, the total emission reductions relative to the Baseline scenario are 43 Gt CO_2. Under this point of view, global deployment of CCS is projected to capture over 10 Gt (19%) of CO_2 emissions in 2050, with a cumulative storage of around 145 Gt CO_2 and 3400 LSIPs CCS projects from 2010 to 2050. For this target the BLUE scenario require urgent implementation of unprecedented and far-reaching new policies in the energy sector.

(3) The pressing urgency of CCS demonstration in the world still remains. The first challenges that a new CCS demonstration project would face are technological and financial uncertainties. CCS has received increase and R&D attention in the last decade as the technology promises to be the most effective for large scale reduction in CO_2 emission in the atmosphere. CCS technologies are no alternatives to better energy efficiency or increased use of non carbon energy sources. As a transitional solution they offer the possibility to make considerable reductions in CO_2 emissions without having to abandon the actual fossil fuel based energy infrastructure within a short time. Operating and electricity costs will increase noticeable if the producers have to restrict venting CO_2 to the atmosphere. Therefore the main priority for the development and widespread application of CCS technology is to minimize the energy requirements and the financial implication of CO_2 injection. Overcoming demonstration challenges will have positive impacts for the subsequent commercial deployment phase. Certainty of deployment incentives will encourage private investment in demonstration projects, and the very demonstration of CCS will enable earlier deployment as technical and economic uncertainties are reduced.

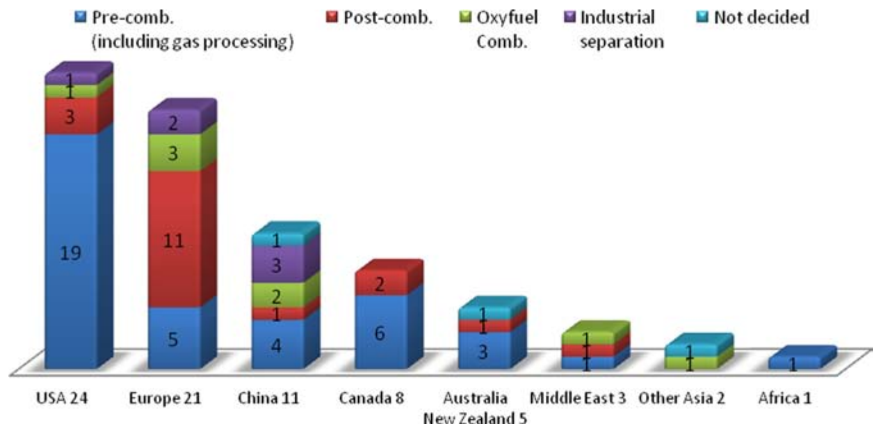


Fig. 23. Distribution LSIPs by region and technology.

Table 8
New identified LSIPs.

Overall asset lifecycle srage	Project name	Country	Technology	Million tonnes CO_2 annually
Identify	Daqing CCS (Datang Group)	China	Super critical PC oxyfuel combustion.	1
Identify	Dongying CCS (Datang Group)	China	PC	1
Identify	Shanxi International Energy Group CCS	China	Super critical PC oxyfuel combustion.	2
Identify	Jilin Oil Field EOR Project (Phase 2)	China	NG	0.8
Identify	Shen Hua Ningxia Coal to Liquid Plant Project	China	Coal-to-liquids (CTL)	2
Identify	Caledonia Clean Energy Project	UK	IGCC	90% plant's CO_2 emissions
Identify	Sargas Green Power Plant Malta	Malta	Fluidised bed boiler	1.2
Identify	Industrikraft Möre AS Norway	Norway	NG	1.4
Define	NRG Energy Parish CCS	USA	Retrofit of post-combustion	1.5

(4) There are 75 large-scale integrated LSIP – CCS projects, by September 2012; more than half of all newly-identified LSIPs are located in China, also there have been two additional projects identified as under construction, in the US and in Canada. Of the 75 LSIPs, 42 occurred in the power generation sector and most of these are planned to occur in coal-fired applications, they will reduce emissions through the application of CCS. Regarding the distributions of LSIP by capture technology: Pre-combustion (included gas processing) represents 52%, followed by Post-combustion and Oxyfuel with 25% and 11% respectively.

9. Importance and recommendations

- This paper attempts to analyze the perspective for the energy demands and the role of the CCS projects, for this reason, we discuss that trade position is a key factor in understanding world's climate strategy for mitigation CO_2 emissions.
- This paper argues that promoting global carbon emission regulations and low – carbon technologies, such as CCS projects. From our assessment framework, it was shown that the CCS Technology will play critical role for mitigation CO_2 emissions at the same time as it allows the continued use of fossil fuel resources such as coal, which plays a role in proving their growing energy demand in the developing countries like China and India.
- The key to embark on the low carbon development pathway is to make low carbon technologies more popular. CCS is a promising technology to achieve high CO_2 emissions reduction from fossil fuel-based power plants; however it is energy-intensive and expensive.
- The maturity and economic competitiveness, the speed and the time when the CCS projects are available will depend the climate change policies on the international and local governments. The government should first promote CCS R&D. After the technology has been developed, relevant incentives can be used to attract more enterprises to apply CCS. For example, the EU increased the R&D input to CCS in order to keep its competitiveness, so it can benefit from future technology export. China is still the biggest coal consumption country in the world, and occupies quite a large proportion in global surge of coal consumption, so China needs to increase CCS technology R&D input in order to avoid paying a higher price to import CCS technology. Therefore, China should establish comprehensive and effective national strategies to promote the development of clean coal and intensify international cooperation.
- The SWOT analysis shows that despite of the weaknesses and threats, strengths and opportunities are greater, especially in terms of opportunities. Develop Capture and storage technologies will be new business opportunities from a technological point of view. As for CO_2 capture processes, a whole new industry is in need to be created for the market in both the industrialized and developing countries. We should take the opportunity as the country is making efforts on energy conservation and emission reduction and on the expansion of their applications in various sectors.
- Finally, the urgency in developing realistic plans for the rapid deployment of the lowest-GHG-emission electricity generation technologies such as CCS. We can and must change our current path, but this will take an energy revolution and low-carbon energy technologies will have a crucial role play. Energy efficiency, many types of renewable energy, carbon capture and storage (CCS), nuclear power and new transportation technologies will all require widespread deployment if we are to reach our GHG emission goals. Every major country and sector of the economy must be involved. The task is also urgent if we are to make sure that investment decisions taken now

and do not saddle us with sub-optimal technologies in the long-term.

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